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Determination, Modeling and Optimization of Distillation Equilibrium of Fermented Palm Wine

BY

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ABSTRACT : *This research work was done using palm wine as a source of fermentable sugar. Equal sample of the palm wine was fermented aerobically by baker's yeast under standard atmospheric condition for consecutive series of 1 to 15 days. Testing and Distillation of liquor was done on each day to determine the amount of fatty acid, PH, sugar, specific gravity and vitamin C, with time during fermentation on one hand and the equilibrium mole fraction relationship for ethanol and water on the other hand. Models were developed to predict the reproduction of the experimental values into future, and, on validationgave* R^2 *which ranges from 0.9901 to 0.9980. On optimization it was revealed that in 1.49 days, 0.1067 percentage fatty acid was produced. With 1.44 percentage mole fraction of ethanol, 3.398 refractive index of palm wine was obtained. It also showed that a minimum of 0.07305 refractive index of distillate per mole fraction of more volatile component was made in just 0.499 percentage mole fraction and a minimum of 0.1956 mole fraction of gaseous ethanol per mole fraction of more volatile component was obtained. The results and models can be applied in the distillation work of this kind for prediction and reproduction of experimental values.*

Key Words: *Palm wine, fermentation, modeling, optimization.*

I. INTRODUCTION

Palm wine has been used locally in Nigeria for ethanol production by rural farmers. Palm wine is an alcoholic beverage obtained from the sap of various species of palm tree and is common, in various part of Africa. In Nigeria, it is abundant in the Niger delta regions and collected by wine tappers. Typically the sap is collected from the cut flowers of the palm tree by a container which is fastened to the flower stump to collect the sap. The wine liquid that initially collects tends to be very sweet and non-alcoholic before it is fermented.

Palm wine (saccharamyces species) has been used for bio-ethanol production at industrial level, and in this work, it is used as the source of fermentable sugar.

This research work covered three stages or processes namely:

(I) Collection and fermentation of palm wine (II) Testing and Distillation of the fermented palm wine and (III) finally modeling and optimization of the results obtained from second stage of the process.

The primary aim of fermentation in this work is to convert the sugar contained in the palm wine to an alcohol (Ethanol) or an acid (Acetic acid) by using yeast, bacteria or a combination there of. Other products that can be gotten from fermentation include lactate and carbon dioxide. The products of fermentation are the basic raw industrial products such as antibiotics, Vitamins, feed supplements and blood plasma expanders etc. Ethanol which is one of the products of fermentation plays a vital role in the economic development of a nation. It can be used as a solvent in extraction process, as an intermediate in the production of liquid detergents, polishes, plasticizers and cosmetics, also as anti-freezers and as fuel.

After fermentation, the next process that was carried out was Testing and Distillation process. The testing was done on the fermented liquor on each day of the fermentation in order to establish the behavior of fatty acid, PH, sugar, specific gravity and vitamin C with time during fermentation. Distillation was also carried out so as to establish a true mole fraction relationship for ethanol and water. The term "Distillation" refers to the physical separation of a

mixture into two or more fractions, based on difference in compositions in liquid phase mixtures of different components into a number of fractions of differing compositions. The objective is usually to separate the solution (mixture) into its components which have negligible contamination or absolutely pure. This separation can be achieved only when there is a difference in composition between a liquid mixture and the vapour in equilibrium above it.

The difference in composition may be analyzed in terms of volatility, vapour pressure or even distribution coefficient. Distillation is thus based on the difference in equilibrium composition between the vapour and liquid phases of a mixture at essentially the same temperature and pressure for the co-existing zones.

Finally, modeling and optimization aspect of the work was carried out. The models were produced as a means or an alternative that should be used in the reproduction of the experimental values.

Fermentation is the metabolic conversion of a carbohydrate such as sugar into an alcohol or an acid using yeast, bacteria or a combination there of. It is also the slow decomposition of organic substances induced by micro-organism or by complex nitrogenous substances (enzymes) of plant and animal origin. Fermentation could occur under anaerobic or aerobic conditions and yields lactate, acetic acid, ethanol, carbon dioxide or some simple products.

The major concern of this research was to establish a true and reasonable equilibrium mole fraction relationship for ethanol and water in one hand and their models and optimizations on the other hand. The research work will also show the behaviors or variation of fatty acid, pH, sugar, and Vitamin C (ascorbic acid) with time during the fermentation of palm wine, and also produced a true and reasonable model for these relationships.

The purpose of this research work was to establish a standard vapour liquid equilibrium curve for water and also for ethanol. The curves represent, toa great deal of accuracy, the general trends in the behavior of liquid ethanol in equilibrium with its vapour, and also the behavoiur of liquid water in equilibrium with its vapour.

Finally, the produced models were aimed at making people get their results easily when working on this topic than passing through the rigorous process of experimental procedures each time.

More so, areas mapped out for treatment will be comprehensively examined. Palm wine will only be obtain from palm trees and no other sources of palm wine, such as, raffia palm trees in this work.

The distillation and fermentation process cut cross many sections of our economy in the following ways:

- The methods are also employed in the manufacturing of alcoholic drinks.
- The methods are also employed in production of antibiotics, vitamins, blood plasma expanders etc.
- The methods are used in the production of food supplements.
- Ethanol which is one of the products of fermentation could be used directly as a solvent for extraction purposes, as an intermediate in the manufacturing of liquid detergents, plastic polishes, plasticizers and cosmetic, as antifreeze and as fuel.

The models produced can also be used for the purposes listed below:

- It can be used in making predictions when fermenting palm wine.
- Used to explain some phenomena that are concerned with the fermentation and distillation of palm wine.
- Be used as bases for decision making whenever there is a need of this types of work.
- Communication between a researcher and the hidden secrets of the work itself.
- Will alleviate the problem of time wastage that is involved in the experimental procedures of this work.

II. EXPERIMENTATION, MODEL DEVELOPMENT AND OPTIMIZATION

2.1 Materials

2.1.1 Collection of palm wine

The palm wine used for this experiment was obtained from Ohukabia village in Awo-Idemili, Orsu Local Government Area of Imo State.

It was collected immediately it was taped from the palm wine tree (Elias Guineansis) so as to avoid any adulteration by addition of water to increase the volume or quantity. This measure was to check any alteration of the physical or chemical composition of

the palm wine, hence ensuring greater accuracy of result.

2.1.2 Apparatus/Reagents used

Refractometer,thermometer,pH meter,measuring cylinder,conical flasks(4),beakers(7),burettes(2) 50ml ,calibrated buckets(3), glass and rubber funnels, pipettes (2) 25ml, electric boiler, manual stove, retort stand, petri-dish, distillation apparatus, cold water(distilled water), palm wine, Baker's yeast, Fehling solution(type A), ascorbic acid, dye solution, methylene blue-indicator, glacial acetic acid, methyl orange-indicator, anhydrous sodium carbonate, chloroform indicator.

2.2 Experimental Procedure

2.2.1 The Fermentation Procedure

Twelve (12) sample of the fresh palm wine each of 250ml in conical flasks were kept open, in a cupboard and allowed to ferment aerobically under standard atmosphere temperature and pressure. Equal amount (2g) of barkers yeast (sacchromycescerevisiae) was added to each sample. The fermentation lasted for a period of 1, 2, 3, 4………..12 consecutive days.

All the analysis to determine the variation in the physical and chemical compositions were carried out at a regular interval of 24hrs for each sample before distillation, but before the introduction of 2g of yeast in the samples of palm wine on the first day, the fresh palm wine was lasted and analyzed to determine its physical and chemical variation.

2.2.2 Distillation procedure

The component of the distillation apparatus were assembled by mounting the distillation flask onto an electric heater connected to a power source with a thermometer inserted into the flask to determine the distillation temperature as clamped onto a retort stand with a flow of a coolant connected counter currently to the flow of the vapour coming into the condenser. A conical flask was also fixed at the mouth of the condenser in order to collect the condensed vapour during boiling. And before any commencement of healthy operation the counter current flow of water in the condenser was tested. Different samples of the fermented palm wine solution (mixtures of ethanol and water) whose physical and chemical compositions had been determined were then heated, and, passing water counter-currently in the condenser. The vapour emanating from the flask were condensed and collected in a conical flask. The temperature at which the first drop of the distillate came out was noted as the required distillation temperature and this temperature was held constant through the distillation in each case. The volume of the condensate (distillates as well as residues were taken while their respective refractive indices were also noted and recorded. This procedure was performed for 12 (twelve) consecutive days using different proportions of sample fermented.

2.2.3 Test for sugar (sucrose)

2.5ml of Fehling solution (type A) was placed in a conical flask, followed by the addition of 15ml of fresh palm wine. Few drops of methylene blue were added to serve as indicator, and then the mixture was boiled with the help of a manual stove.

At an interval of 20 seconds, little of the fresh palm wine was added to the boiling mixture until the blue colour disappeared to give a pale yellow colour. This process was carried out before and after fermentation in each case before distillation.

By analysis using the non-stoichiometric method (Lare and Eynon 1923).

Sucrose content in sugar = 95%

$$:. \%\ sucrose = \frac{1000}{Palm\ wine\ used} \text{x} \frac{95}{100} = \frac{1000}{Palm\ wine\ used} x\ 0.95$$

2.2.4Test for fatty acid

A small quantity of anhydrous sodium carbonate (powder) was placed in a Petri-dish and a drop of palm wine was added. As the sodium carbonate is dissolving, effervescence occurred to indicate the presence of a carboxylic group (fatty acid).

For the titration to determine the amount of fatty acid present, 1.325g of anhydrous (powdered) sodium carbonate was dissolve in 250ml of water to form a 0.05m solution of the alkalis. 25ml of this mixture was then

measured with the help of a pipette and poured into a conical flask having filled the burette with palm wine up to the 50cm mark and clamped it to a resort stand. This was followed by titrating the sodium carbonate solution against the palm wine in the burette after some few drops of methyl orange was added as indicator, until a pale yellow colour was obtained as end point.

This procedure was carried out before and after fermentation in each case.

Using the non-stoichiometric volumetric method of analysis, it is seen that:

% total fatty acid $= 0.015\,(P + 1.50)$

Where p = Average titer of palm wine.1.50 And 0.015 are constants.

2.2.5Test for vitamin C (Ascorbic acid)

5ml of palm wine was measured and poured into a beaker with the help of pipette, and 1ml of glacial acetic acid added into the sample. 1ml of chloroform was added to serve as an indicator. A dye sodium, was pourred into the burette clamped to a resort stand and was then titrated against the mixture until a colour change was observed. This procedure was repeated but this time by titrating a 0.05M solution of ascorbic acid against the mixture of glacial acetic acid, chloroform and palm wine until a change in colour was also observed.

By analysis, the actual amount of Vitamin C is obtained as follows:

$$Vitamin\ C = \frac{Average\ titer\ of\ dye\ \times 2 \times dilution}{Average\ titer\ of\ acid}$$

Where Dilution = the amount of water used for diluting the dye solution.

This procedure was repeated each day before distillation.

2.2.6Determination of pH Value

100ml of palm wine solution was pourred into a 250ml capacity beaker and the tip of the electronic P^H meter made to dip directly into the solution having switched the power on. A steady value appeared on the screen and was recorded as the P^H value of the fresh palm wine. This procedure was repeated in each case before distillation (that is after fermentation). Result is also tabulated in the experimental result section.

2.2.7Measurement of Temperature

This was done with the help of a thermometer (Mercury-in-glass thermometer). The thermometer was dipped into the solution of palm wine and any rise recorded. This process was carried out at a regular interval of 24 hours throughout the period of fermentation.

2.2.8Test for Refractive Index

A small quantity of palm wine was placed on the screen of the refractometer. Readings were taken by viewing through the eyepiece of the instrument until a sharp demarcation was observed between the two images formed. Any reading displayed on the scale at this point was recorded as the refractive index of the sample in question by this method, the refractive index of the fermented palm wine samples and that of the fresh palm wine was taken. Also this method was used to find the refractive index of the distillates and residues after distillation in each case.

2.2.9 Measurement of Specific Gravity

This was obtained by firstly weighing a 200ml flask, followed by weighing it when it was filled with water and also when it is filled with palm wine. Then the specific gravity was calculated by dividing the weight of palm wine by the weight of equal volume of water. This procedure was carried out on the fresh palm wine and on each sample of fermented palm wine that was subjected to distillation.

2.3Development of Models

2.3.1 Variation of Sugar Content versus Time (Days)

The change in time is proportional to the natural log of change of the reciprocal of sugar content.

ie $\quad \Delta t\ \alpha\ In\left(\Delta\, {}^{1}\!/_{S}\right)$

$$t - t_o\ \alpha\ In\left({}^{1}\!/_{S} - {}^{1}\!/_{S_o}\right)$$

$$t - t_o = b\, In\left(1/_s - 1/_{s_o}\right)$$
$$In\left(1/_s - 1/_{s_o}\right) = \frac{t - t_o}{b}$$
$$1/_s - 1/_{s_o} = e^{((t-t_o)/b)}$$
$$s = {s_o}\Big/\left(1 + s_o e_{xp}{}^{(t-t_o)/b}\right) \quad 2.1$$

2.3.2 Fatty Acid versus Time of Fermentation

i) The fatty acid is partially a constanti.e.$y = a_0$.

ii) It is also partially proportional to the decline of negative exponential of time raise to a constant poweri.e $y = -A_{exp}(-a_2 x^n)$

Combining the variations after simplification yields:

$$y = a_o\left(1 - a_1 e_{xp}(-a_2 x^n)\right) \quad 2.2a$$

Where $A = a_o a_1$

2.3.3 Refractive Index of Fermented palm wine versus Mole Fraction of Ethanol in Gaseous Phase

The variation of refractive index of fermented palm wine with mole fraction of ethanol in gaseous phase obeys the same model as equation (3.2a) above, only that it is also partially proportional to a yet an additional constant K.

$$R_i = a_o\left(1 - a_1 e_{xp}(-a_2 x^n) + K\right) \quad 2.3$$

2.3.4Refractive Index of Distillate (R_i) versus Mole Fraction of Ethanol in Liquid Phase (X_A), Mole Fraction of Ethanol in Gaseous Phase (Y_A) versus Mole Fraction of Ethanol in Liquid Phase (X_A), and Mole Fraction of Water in Gaseous Phase (Y_B) versus Mole Fraction of Water in Liquid Phase (X_B).

In these relations above, the independent variable is partially proportional to the cube of the dependent variable, partially proportional to the square of the dependent variable and partially proportional to the dependent variable and partially a constant.

Combining all these yields a cubic polynomial, $y = ax^3 + bx^2 + cx + d$.

$$\therefore y = ax^3 + bx^2 + cx + d$$
$$or\ y = p_1 x^3 + p_2 x^2 + p_3 x + p_4 \quad 3.4a$$

2.3.5 Variation of pH with Time of Fermentation

The P^H of fermented palm wine is directly proportional to a quadratic function of time ($P_1x^2 + P_2x + P_3$), and inversely proportional to a linear function of time ($x + q_1$).

Combining the variations yields:

$$\mathrm{P^H} = \frac{P_1x^2 + P_2x + P_3}{x + q_1} \quad 3.5$$

2.4 Optimization of Models

2.4.1 When model equation 3.2a above

i.e. $y = a_o\left(1 - a_1 exp^{-a_2x^n}\right)$is optimize, the first derivative becomes

$$\Delta y = n a_o a_1 a_2 x^{n-1} exp^{-a_2 x^n} \quad 3.2b$$

When we equates the second derivative to zero, $\left(i.e.\ \Delta^2 y = {d^2y}/_{dx^2} = 0\right)$, we obtain

The pick point $x_{opt} = \left(\frac{n-1}{na_2}\right)^{1/n}$ 3.2c

3.4.2 When model three (i.e. equation 3.3) is optimized, it behaves like model (3.2a) and yields same result.

3.4.3 When equation (3.4a) above ($i.e.\ y = ax^3 + bx^2 + c_x + d$) is optimized, the first derivative becomes

$$\Delta y = 3ax^2 + 2bx + c \quad 3.4b$$

And from second derivative

$\Delta^2 y = {d^2 y}/{dx^2} = 0,$

We obtained:

$x_{opt} = -{b}/{3a}$ 3.4c

2.5 Curve Fitting

The models were superimposed on the scatter diagram of the experimental data to ascertain their fitness and statistical goodness of fit using MatLab package 7.9 version.

III. RESULT PRESENTATION AND DISCUSSION

3.1 Result presentation

The result of the experiments and curve-fittings done in the previous section are presented here below in tables 3.1 - 3.10 and figures3.1- 3.8, and their consequent tables 3.11 - 3.17.

Table 3.1: Variation of Sucrose (Sugar) Content with Time of Fermentation

Time (days)	Amount of palm wine used (ml)	Sucrose content (%)
0	72.96	13.03
1	74.22	12.80
2	77.87	12.20
3	84.29	11.27
4	98.96	9.60
5	119.52	7.96
6	152.00	6.27
7	209.30	4.54
8	375.50	2.53
9	593.75	1.60
10	-	0.00
11	-	0.00
12	-	0.00

Table 3.2: Variation of Fatty acid (Carboxylic acid) with Time of Fermentation

Time (days)	Average palm wine titer (ml)	Fatty acid content (%)
0	7.83	0.140
1	15.17	0.250
2	24.83	0.395
3	26.50	0.420
4	35.17	0.550
5	44.50	0.690
6	48.70	0.753
7	51.57	0.796
8	53.50	0.825
9	54.57	0.841
10	55.17	0.850
11	55.17	0.850
12	55.17	0.850

Table 3.3: Variation of Ascorbic acid (Vitamin C) with Time of Fermentation

Time (days)	Ascorbic acid titer (ml)	Dye titer (ml)	Vitamin C (mg/100ml)
1	9.60	14.52	10.20
2	10.21	17.63	10.20
3	10.52	19.49	10.40
4	10.80	21.36	10.80
5	11.10	23.45	11.15
6	11.22	24.76	11.60
7	11.26	25.85	12.20
8	11.30	27.25	13.00
9	11.44	31.05	14.90
10	11.52	33.05	15.80
11	11.64	36.30	17.22
12	11.84	40.39	18.60
13	11.84	40.39	18.60

Table 3.4: Determination of calibration curve

Mixed Solution		Total (ml)	Mole Fractions		Refractive Index
Water	Ethanol		X_A	X_B	
19	1	20	0.95	0.05	1.3484
18	2	20	0.90	0.10	1.3670
17	3	20	0.85	0.15	1.3855
16	4	20	0.80	0.20	1.4040
15	5	20	0.75	0.25	1.4225
14	6	20	0.70	0.30	1.4410
13	7	20	0.65	0.35	1.4595
12	8	20	0.60	0.40	1.4780
11	9	20	0.55	0.45	1.4965
10	10	20	0.50	0.50	1.5150
9	11	20	0.45	0.55	1.5350
8	20	20	0.40	0.60	1.5520
7	13	20	0.35	0.65	1.5705
6	14	20	0.30	0.70	1.5890
5	45	20	0.25	0.75	1.6075
4	16	20	0.20	0.80	1.6260
3	17	20	0.15	0.85	1.6445
2	18	20	0.10	0.90	1.6630
1	19	20	0.05	0.95	1.6815

Table 3.5: Mode Fraction Composition in Gaseous phase

Time (days)	Refractive index of Fermented wine	Refractive Index		MoleFraction	
		Residues	Distillate	Y_A	Y_B =1-Y_A
1	1.3500	1.3301	1.3837	0.145	0.855
2	1.3666	1.3301	1.4447	0.310	0.690
3	1.3850	1.3300	1.4965	0.450	0.550
4	1.4001	1.3301	1.5317	0.500	0.500
5	1.4220	1.3302	1.5500	0.600	0.400
6	1.4410	1.3301	1.5670	0.640	0.360
7	1.4600	1.3300	1.5750	0.660	0.340
8	1.4800	1.3300	1.5890	0.700	0.300
9	1.5050	1.3300	1.6001	0.730	0.270
10	1.5600	1.3300	1.6223	0.790	0.210
11	1.5890	1.3301	1.6334	0.820	0.180
12	1.6350	1.3300	1.6559	0.880	0.120

Table 3.6: Mole Fraction composition in Liquid Phase

Time (days)	Refractive Index		Mole fraction Composition	
	Residues	Distillate	X_A	X_B = 1- X_A
1	1.3301	1.3837	0.050	0.950
2	1.3301	1.4447	0.099	0.901
3	1.3300	1.4965	0.150	0.850
4	1.3301	1.5317	0.200	0.800
5	1.3302	1.5500	0.250	0.750
6	1.3301	1.5670	0.300	0.700
7	1.3300	1.5750	0.350	0.650
8	1.3300	1.5890	0.400	0.600
9	1.3300	1.6001	0.550	0.450
10	1.3300	1.6223	0.640	0.360
11	1.3301	1.6334	0.700	0.300
12	1.3300	1.6559	0.770	0.270
13	1.3300	1.6667	0.790	0.210

Table 3.7: Vapour-Liquid Equilibrium Curve-Ethanol

Mole Fraction of Ethanol in liquid phases (x_A)	0.050	0.099	0.150	0.200	0.250	0.300	0.355	0.400	0.550	0.640	0.700	0.770	0.790
Mole fraction of Ethanol in gaseous phase ($y_{A(1)}$)	0.145	0.310	0.450	0.545	0.600	0.640	0.660	0.700	0.730	0.790	0.820	0.880	0.910

Table 3.8: Vapour-Liquid Equilibrium Curve-Water

Mole Fraction of Ethanol in liquid phases (x_B)	0.950	0.901	0.850	0.800	0.750	0.700	0.650	0.600	0.450	0.360	0.300	0.270
Mole fraction of Ethanol in gaseous phase (y_B)	0.855	0.690	0.550	0.450	0.400	0.360	0.340	0.300	0.270	0.210	0.180	0.120

Table 3.9: Variation of pH with Time of Fermentation

Time (days)	0	1	2	3	4	5	6	7	8	9	10	11	13
pH	6.56	6.21	5.93	5.67	5.37	5.20	4.94	4.78	4.66	4.53	4.50	4.50	4.50

Table 3.10:Variation of Specific Gravity with Time ofFermentation

Specific gr.	0.985	0.930	0.880	0.825	0.775	0.720	0.670	0.620	0.565	0.513	0.460	0.390	0.305	0.305
Time (days)	0	1	2	3	4	5	6	7	8	9	10	11	12	13

Curve Fittings

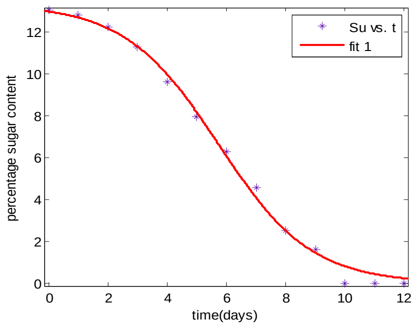

Figure 3.1: Percentage sugar content versus time duration of fermentation

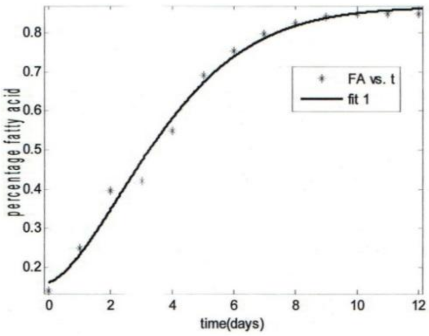

Figure 3.2a: Percentage fatty acid versus time of fermentation

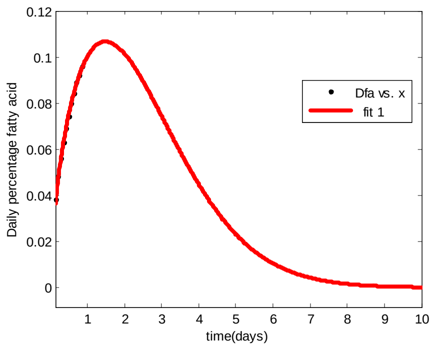

Figure 3.2b: Percentage fatty acid versus time of fermentation

Table 3.11: Coefficients and goodness of fit, for fig 3.1

95% Coefficient Bound	**Goodness of Fit**
S_0= 13.3 b= 1.57 t_0= 9.778	SSE = 1.39 R^2 = 0.9956 R^2 Adj.= 0.9948 RMSE = 0.3728

Table 3.12: Coefficients and goodness of fit, for fig 3.2b

95% Coefficient Bound	**Goodness of Fit**
a_0= 0.8662 a_1= 0.8135 a_2= 0.1034 n= 1.564 t_{opt}: F(1.49)= 0.106662	SSE = 0.007565 R^2 = 0.9901 R^2 Adj.= 0.9868 RMSE = 0.02899

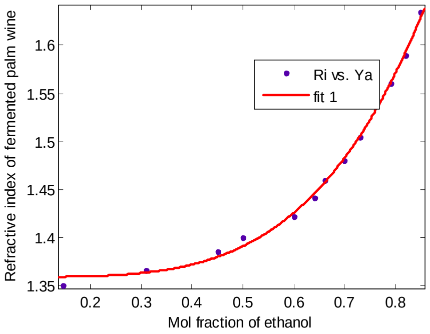

Figure 3.3a: Refractive index of fermented palm wine versus mole fraction of ethanol

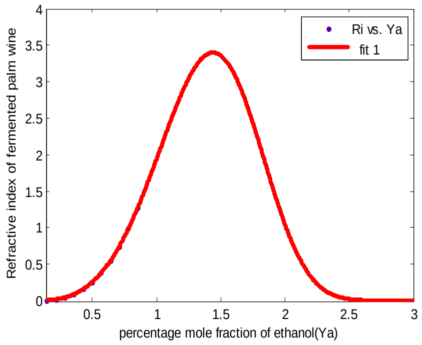

Figure 3.3b: Refractive index of fermented palm wine versus mole fraction of ethanol in gaseous phase

Table 3.13: Coefficients and goodness of fit, for fig 3.3b

95% Coefficient Bound	Goodness of Fit
a_0= 6.868 a_1= 1.036 a_2= 0.07497 K = 1.607 n= 4.067 Y_{opt}: F(1.44)= 3.39777	SSE = 0.0003058 R^2 = 0.9966 R^2 Adj.= 0.9947 RMSE = 0.006609

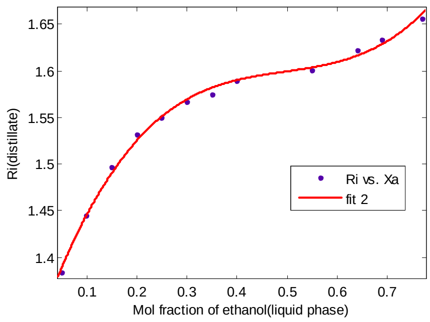

Figure 3.4a: Refractive index of distillate versus mole fraction of ethanol (liquid phase)

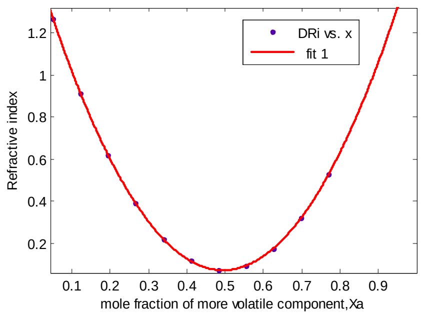

Figure 3.4b: Refractive index per mole fraction of more volatile component versus mole fraction of more volatile component in liquid phase (Xa)

Table 3.14: Coefficients and goodness of fit, for fig 3.4b

95% Coefficient Bound	Goodness of Fit
P_1 = 2.011 P_2 = -2.988 P_3 = 1.552 n= 1.318 X_{opt}: F(0.499)= 0.0730508	SSE = 0.0002376 R^2 = 0.9966 R^2 Adj.= 0.9953 RMSE = 0.00545

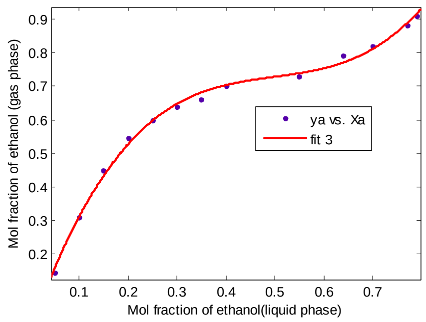

Figure 3.5a: Vapour-Liquid equilibrium for ethanol during fermentation of palmwine

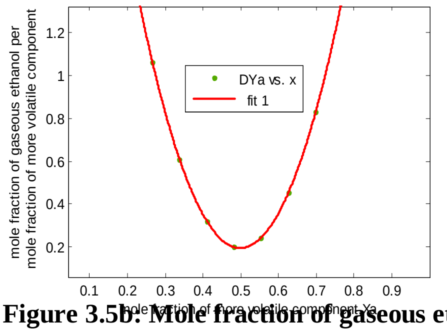

Figure 3.5b: Mole fraction of gaseous ethanol per mole fraction of more volatile component versus mole fraction of more volatile component in liquid phase

Table 3.15: Coefficients and goodness of fit, for fig 3.5b

95% Coefficient Bound	Goodness of Fit
$P_1 = 5.319$ $P_2 = -7.961$ $P_3 = 4.167$ $P_4 = -0.03022$ X_{opt}: F(0.499)= 0.195602	SSE = 0.001921 $R^2 = 0.9968$ R^2 Adj.= 0.9957 RMSE = 0.01461

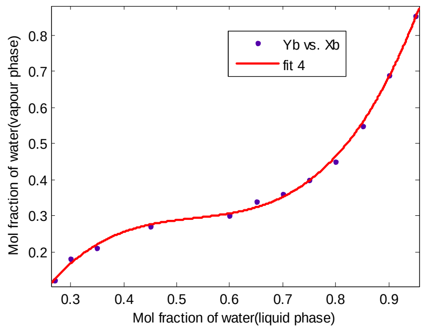

Figure 3.6a: Vapour-Liquid equilibrium for water during fermentation of palmwine

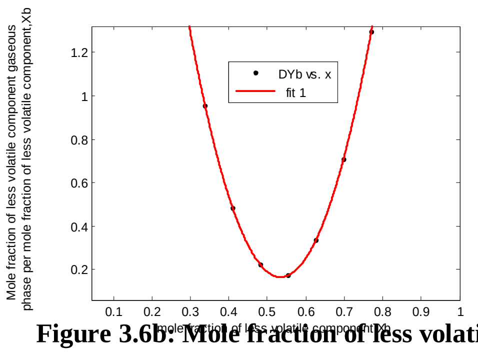

Figure 3.6b: Mole fraction of less volatile component in gaseous phase per mole fraction of less volatile component in liquid phase versus mole of less volatile component(Xb)

Table 3.16: Coefficients and goodness of fit, for fig 3.6b

95% Coefficient Bound	Goodness of Fit
$P_1 = 6.802$ $P_2 = -10.91$ $P_3 = 6.004$ $P_4 = -0.8353$ X_{opt}: F(0.535)= 0.165855	SSE = 0.001046 $R^2 = 0.9980$ R^2 Adj.= 0.9972 RMSE = 0.01143

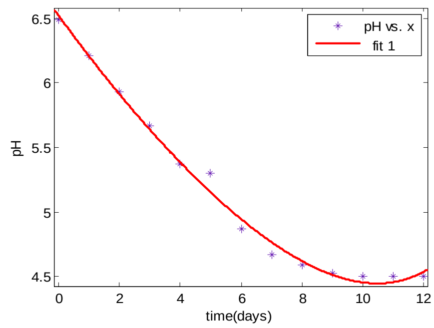

Figure 3.7: Variation of pH of palm wine with time during fermentation

Table 3.17: Coefficients and goodness of fit, for fig 3.7

95% Coefficient Bound	Goodness of Fit
$P_1 = 21.08$ $P_2 = -475.1$ $P_3 = 8529$ $Q_1 = 1295$	SSE = 0.006773 $R^2 = 0.9989$ R^2 Adj.= 0.9985 RMSE = 0.02743

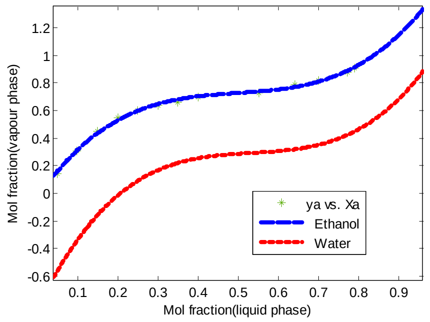

Figure 3.8:Vapour-Liquid equilibrium for ethanol and water during palmwine fermentation

IV. Discussion of Result

From figure 4.1 and its consequent table 4.11, it is clear that the percentage sugar content decreases exponentially with time. The model (eqn. 3.1) used on it gave a correlation of 0.9956 to show that it is a good model.

In figure 4.2, the percentage fatty acid increases with time in days as a natural growth model. The model used on it (equation 3.2a) gave a very good correlation, of 0.9901.On optimization; figure 4.2b shows a daily percentage fatty acid against time in days. It reveals a daily percentage fatty acid of 0.107 in 1.5 days.

Figure 4.3a shows a refractive index of fermented palm wine against mole fraction of ethanol in gaseous phase. Again, it behaves like a natural growth profile. On optimization, figure 4.3b result gives a peak at 1.44% mole fraction of ethanol to yield 3.398 refractive index of fermented palm wine. The model was pretty good as it reflect as much as 99.66% of the experimented value as shown by the R^2 in figure 4.4a. On optimization, however, the model gave a trough in figure 4.4b. This trough gave a minimum point of 0.499 mole fraction of more volatile component to 0.0731 refractive index of distillate per more fraction of more volatile component.

In figure 4.5a, a plot of mole fraction of ethanol in gaseous phase against mole fraction of ethanol in liquid phase, like figure 4.4a, was made. When model is plotted against the data it (equation 3.4a) gave an accuracy of 99.68% of the experimental characteristics. On optimization, it gave a trough of 0.499 mole fraction of more volatile component as against 0.1956 mole fraction of gaseous ethanol per-fraction of more volatile component in 4.5b.

Also, in figure 4.6a, a plot of mole fraction of water (vapour phase) against mole fraction of water (liquid phase) was made. The model gave an accuracy of R^2 = 0.9960 of the experimental characteristics. On optimization, a trough yielded to give a minimum of 0.535 mole fraction of less volatile component against 0.1659 mole fraction of less volatile component (gaseous phase) per mole fraction of less volatile component. Again, figure 4.7 is a plot of P^H against time (day) of palm wine during fermentation. The model (equation 3.5) captured as much as an accuracy of 0.9989 of the experimental characteristics.

Finally, figure. 4.8 is a plot of mole fraction of ethanol and water (vapour phase) against mole fraction of the same ethanol and water (liquid phase).

The plot shows the relationship between ethanol and water variation during fermentation of palm wine.

V. CONCLUSSION

In this project, experiment was done to determine the variation of (i) sugar content, (ii) Fatty acid, (iii) Ascorbic acid, (iv) pH,etc. with time during the fermentation of palm wine.The vapour-liquid equilibrium was also determined using the distillation process.

Models were developed to predict and enhance the reproduction of the experimental values. On curve fittings, the models fitted very well into the parameter variation of the palm wine fermentation as given by the R^2 which ranges from 0.9901 to 0.9980.

An optimization carried out shows that in 1.49 days, 0.1067 daily percentage fatty acid is produce. In 1.44% mole fraction of ethanol, 3.398 refractive index of palm wine is obtained.More so, a minimum value of 0.07305 refractive index of distillate per mole fraction of more volatile component was obtain in just 0.499% mole fraction of the more volatile component in liquid phase .

Finally, in the same 0.499% mole fraction of ethanol (liquid phase), a minimum value of 0.1956 mole fraction of more volatile component was obtained. With these optimal values, application of the result in the reproduction of the experiment is imperative.

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